

ECOSYSTEM SERVICES IN A REGULATED RIVER: VARIABILITY IN NUTRIENT UPTAKE AND NET ECOSYSTEM METABOLISM IN THE CHATTAHOOCHEE RIVER

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Abstract. Rivers provide vital ecosystem services that are often difficult to quantify economically and overlooked by management agencies. Two of these services, nutrient uptake and net ecosystem metabolism, are especially important in urban rivers receiving large quantities of point source discharge. However, little is known about the mechanisms that facilitate these ecosystem processes in large, regulated rivers such as the Chattahoochee. We examined how nutrient uptake and net ecosystem metabolism varied under different baseflows on the Chattahoochee River downstream of Atlanta. Nutrient uptake was measured as uptake length, the average distance traveled downstream by a nutrient molecule before it is removed from the water column. Our results showed that nutrient uptake length was variable, but often exceeded the length of the river between the major Atlanta dischargers and West Point Lake. This means that phosphorous entering in effluent was not removed from the river before it entered West Point Lake. Net ecosystem metabolism data indicated that the Chattahoochee below Atlanta is a highly heterotrophic system, but respiration appears to decrease under lower discharge.

INTRODUCTION

Ecosystem services represent the benefits human populations derive, directly or indirectly, from ecosystem functions (Constanza et al. 1997). In many instances, these services are difficult to quantify economically and are overlooked by management agencies. Streams provide a variety of ecosystem services. In particular, streams retain and transform nutrients and process organic matter entering from the catchment. In urban catchments, the uptake of nutrients and processing of organic matter are essential and necessary ecosystem services provided by streams to the surrounding human communities. In addition, these processes are essential for good water quality and

ecosystem health both in the immediate stream and for downstream systems and communities.

The in-stream processing of nutrients and organic matter can become especially critical when other mechanisms for assimilating these inputs are removed. For example, riparian zones are bypassed by point source discharges, and as a result any nutrient uptake, transformation, or retention and of nutrients and organic matter that might occur in this zone is removed. Point source discharges are particularly prevalent on the Chattahoochee River below Atlanta, GA. During summer baseflow at the Highway 92 crossing, 22% of the flow is wastewater treatment plant effluent (USACE 1998). Hence, in-stream processing of nutrients and organic matter in this effluent provides a direct benefit to local and downstream communities.

BACKGROUND

The uptake and movement of nutrients and energy in an ecosystem are fundamental processes, and in rivers the transport and transfer of nutrients are tightly linked with the physical movement of water. In flowing waters, nutrient cycles are longitudinally extended to become spirals (Webster and Ehrman 1996). The length of the spiral is primarily determined by uptake length, which is strongly correlated with stream velocity (Newbold et al. 1983, Meyer and Edwards 1990, Webster and Ehrman 1996). Uptake length is a measure of the distance it takes the average nutrient molecule to be incorporated into biomass or a particle. Uptake length is the inverse of the slope of the curve resultant from the relationship between the natural logarithm of the nutrient:chloride ratio measured at each sampling site (after background correction) and the distance between the specific sampling site and the site of nutrient input. Greater hydrologic variability can lead to large variations in the turnover lengths of nutrients (Meyer and Edwards 1990). Therefore, flow directly influences the movement of nutrients in a

system, and changes in flow will influence the transport of nutrients to downstream ecosystems.

The fixation of energy through production and the subsequent release through respiration are also primary ecosystem functions, and the addition or loss of energy to the system can influence energy flows in downstream systems. In order to determine net energy addition or loss to the system, net ecosystem metabolism can be calculated. Net ecosystem metabolism is defined as the difference between gross primary productivity and total system respiration (Bott 1996). Metabolism has been shown to vary with high stream discharge as a result of shifts in primary production (Uehlinger and Naegeli 1998). However, relationships between net daily metabolism and discharge under low flow conditions are uncertain, particularly in large river systems.

METHODS

Study Site

The Chattahoochee River between the Highway 166 crossing and Franklin, GA, is a wide fairly swift river with relatively steep banks. For the most part, the riparian zone is intact and large woody debris often falls into the river. Substrate on this section of the river is highly variable consisting of sand, clay, cobbles and occasional boulders which are associated with the fault lines. This section of the river is highly regulated by both Buford and Morgan Falls dams. Summer baseflow is determined by the operations of these dams, and as a result there is high within and between day variability in discharge. Turbidity and nutrient concentrations are relatively high.

Nutrient Uptake Length

Nutrient uptake length was measured using the methods described by Webster and Ehrman (1996) and Stream Solute Workshop (1990). We used effluent of wastewater treatment plants as the source of the conservative tracer (chloride, Cl^-) and soluble reactive phosphorus (SRP) (Marti et al. in press). We sampled SRP, and Cl^- concentration at one site above and five sites below the major municipal discharges from Atlanta on four different days during summer 2000. The most upstream site was the Highway 166 crossing; the next four sites were 5.2, 21.8, 39.1, and 46.6 km downstream respectively. The site above Atlanta was used to correct for background concentrations. All samples were taken during baseflow, filtered in the field with Gelman A/E glass fiber filters, and stored on ice for transport to the lab. Samples were then frozen until nutrient analysis could be performed. SRP concentration was determined using the colorimetric methods of Wetzel and Likens (1992). Chloride was determined with an ion chromatograph (UGA Soil Ecology Lab). Nutrient uptake length is the inverse of the slope of the regression line between distance (km) and $\ln(\text{nutrient} : \text{chloride ratio})$ after correcting for background concentrations (Webster and Ehrman 1996). In cases where the nutrient : chloride ratio increased downstream we assumed that there was no uptake, since this implies a net release of SRP from the sediments.

Net Ecosystem Metabolism

We determined net daily metabolism for a 1.4 km reach just above Highway 166 using the upstream-downstream diurnal dissolved oxygen change technique (Marzolf et al. 1990, Young and Huryn 1998). We

Table 1. SRP uptake length for the 46 km reach below the Highway 166 crossing. Net Ecosystem Metabolism for a 1.4 km reach upstream of the Highway 166 crossing.

Date	Discharge (m^3/s)	Temperature ($^{\circ}\text{C}$)	Initial SRP concentration ($\mu\text{g}/\text{l}$)	SRP uptake (km)	Gross Primary Production ($\text{mg O}_2 \text{ l}^{-1} \text{ h}^{-1}$)	Respiration ($\text{mg O}_2 \text{ l}^{-1} \text{ h}^{-1}$)	Net Ecosystem Metabolism ($\text{mg O}_2 \text{ l}^{-1} \text{ h}^{-1}$)
June 26	46	24.6	61.80	104	1.89	6.43	-4.54
July 3	28	26.1	41.20	No uptake	1.02	1.50	-0.48
July 17	32	28.5	112.97	232	1.47	6.07	-4.60
Sept 10	37	26.3	66.50	No uptake	1.65	6.27	-4.62

determined travel time for a variety of discharges by floating oranges from the upstream to downstream station. Travel time was estimated from the median orange. We continuously measured dissolved oxygen and temperature using a Hydrolab dissolved oxygen probe for a 40-hour period. Oxygen concentrations were corrected for diffusion using the energy dissipation model (APHA 1992). Channel slope for this model was determined by using 1:24,000 USGS topographic maps and determining the average slope for the river between Atlanta and West Point Lake.

Gross primary productivity and community respiration were calculated using standard methods (Bott 1996). Discharge was determined from the USGS Real-time gauging station near Fairburn, GA (USGS station 02337170). We measured metabolism and nutrient uptake over the same time period to determine if metabolism and nutrient uptake respond in a similar manner to changes in flow and to determine if there is a relationship between the two.

RESULTS

Nutrient uptake length

Uptake length for SRP ranged from 104 km to no uptake (Table 1). There was no detectable relationship between discharge and uptake length. In addition, there was no detectable relationship between uptake length and initial SRP concentration (Table 1).

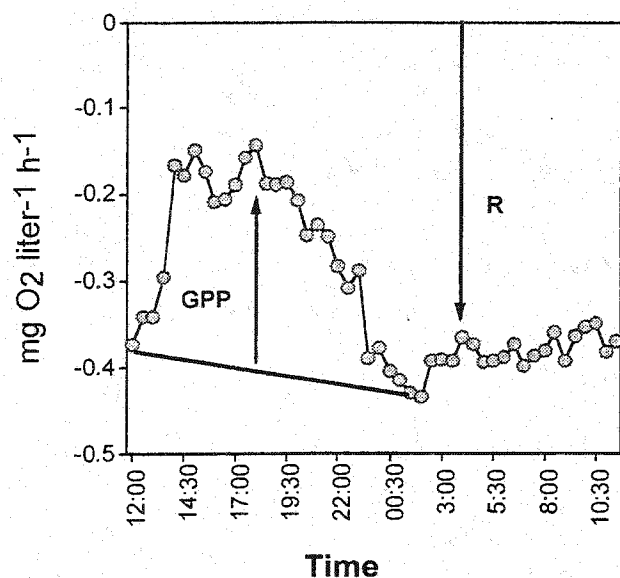


Figure 1. Net ecosystem metabolism on June 26, 2000 for the Chattahoochee River at Highway 166. Notice that respiration always exceeds gross primary production.

Net ecosystem metabolism

The Chattahoochee River at the Highway 166 crossing is a highly heterotrophic system. For these four sampling dates, total respiration always exceeded gross primary productivity. Thus the P/R ratio was less than 1 and net ecosystem metabolism was negative. Respiration exceeded gross primary productivity for the entire 24-hour period on 3 out of 4 sampling dates (Table 1). On these 3 dates, more oxygen was being consumed by respiration even though there was evidence of gross primary productivity occurring (Figure 1). On the other date, July 3, gross primary productivity created more oxygen than was consumed by respiration for a short time. There was no clear trend between net ecosystem metabolism and discharge; although, respiration rates increase with discharge. In addition, there was no clear trend between metabolism and phosphorous uptake length.

DISCUSSION

The Chattahoochee River at Highway 166 is a highly heterotrophic system. SRP uptake length for this 46 km reach of the river ranged from no uptake at all to 232 km. Highly negative NEM, low P/R ratios, and high rates of respiration demonstrate that this system is fueled by allochthonous carbon and that a large amount of organic matter processing is occurring. In contrast, long uptake lengths and evidence of a lack of uptake suggests that there is little assimilation of the nutrients from the wastewater treatment plants.

SRP uptake lengths (104 and 232 km) in this study were almost two orders of magnitude longer than those found in a river with similar discharge, but not receiving any waste water treatment plant effluent (1.5 km) (Butturini and Sabater 1998). Third order Mediterranean streams receiving wastewater treatment plant effluent also had much longer SRP uptake lengths than non-polluted streams with similar discharge (Marti et al. in press). Similar to our study, phosphorous concentrations in the Mediterranean streams receiving effluent did not consistently decline downstream in 33% of the cases (Marti et al in press). In our study, the instances of no measurable uptake were associated with an increase in phosphorous concentrations in the downstream direction and a concomitant positive relationship between phosphorous : chloride ratio and distance downstream. This increase in phosphorous concentrations could be caused by the flux of phosphorous out of the sediments (Reddy et al. 1996).

The long uptake lengths as well as the increase in phosphorous concentrations downstream in this reach of the river have major implications for water quality in West Point Lake. The distance between the Highway 166 crossing and Franklin, GA (the site of the river/reservoir transition) is 76 km. The shortest uptake length measured in this study was 104 km. Therefore, the average phosphorous molecule will have not been assimilated prior to reaching West Point Lake. This means that a majority of the phosphorous from Atlanta's municipal wastewater facilities is directly discharged into West Point Lake. This high phosphorous loading could lead to eutrophication of the reservoir and algal blooms. In addition, these long uptake lengths indicated that the river may no longer be capable of retaining and transforming phosphorous during some times of the year. Therefore, the river is no longer capable of providing the service of nutrient assimilation to downstream communities.

In contrast, organic matter processing rates seem fairly high. P/R ratios ranged from 0.2 to 0.4 indicating that this is a heterotrophic system, which is dominated by allochthonous inputs. These P/R ratios are well within the range of P/R ratios (0.02 to 0.4) found in the Ogeechee River, which is dominated by allochthonous organic matter inputs from the floodplain (Meyer and Edwards 1990).

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